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BIRDS POINT-NEW MADRID FLOODWAY, EMERGENCY OPERATION: EXPLOSIVE--ETC(U)
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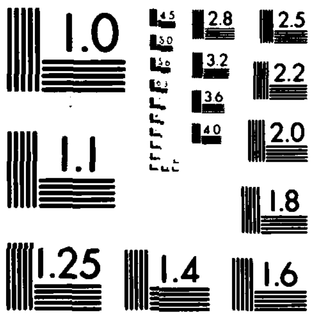

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MISCELLANEOUS PAPER SL-80-5

BIRDS POINT-NEW MADRID FLOODWAY EMERGENCY OPERATION EXPLOSIVE DESIGN SUMMARY

by

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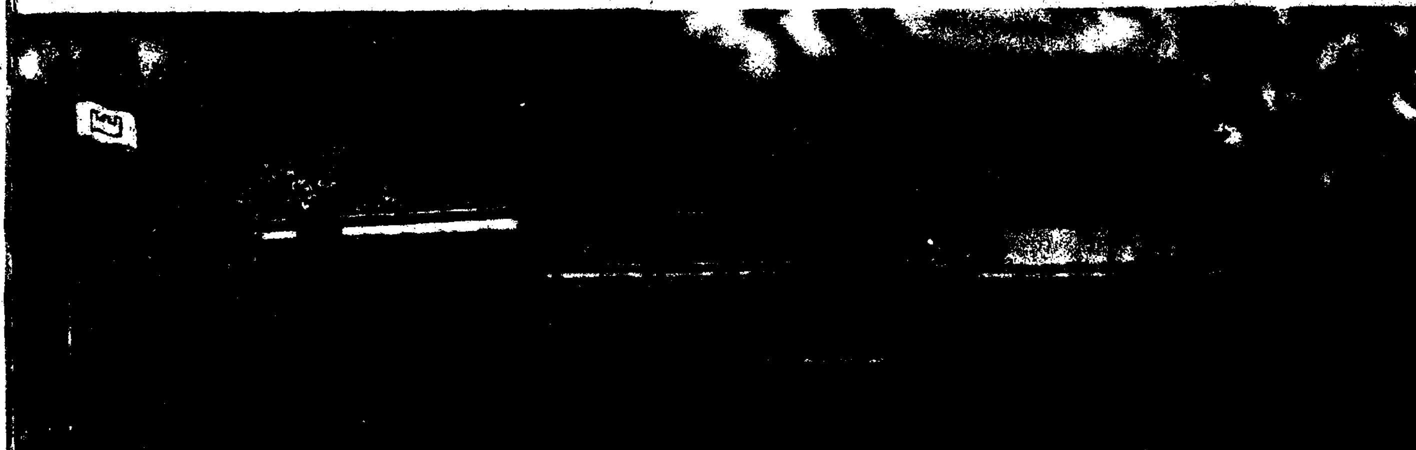
April 1980

Final Report

Approved For Public Release; Distribution Unlimited



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At the request of the Mississippi River Commission, a design was prepared by the U. S. Army Engineer Waterways Experiment Station (WES) for the explosive excavation of a length of levee, part of an emergency operation plan for the Birds Point-New Madrid Floodway in the U. S. Army Engineer District, Memphis. Field tests leading to the explosive design were conducted at the WES Big Black Test Site, and consisted of four phases: (a) detonating cord layout, (b) full-scale borehole loading of candidate explosives, (c) a one-third-scale model,

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and (d) longitudinal spacing. From tests of commercial slurry explosives recommended by manufacturers, an explosive was selected for the excavation, and a layout and borehole depth were determined, based upon expected crater size, for an array of three rows of vertically emplaced, water-stemmed charges. Alternate slurries and accompanying spacings are included.

PREFACE

This study was sponsored by the Mississippi River Commission (MRC) and was conducted during the period April-December 1979. The report was prepared by Mr. A. D. Rooke, Jr., of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES).

Special recognition is due the following WES personnel: CPT G. A. Woodbury, who designed and conducted much of the field testing; Mr. H. D. Carleton, whose knowledge of both commercial slurries and the Birds Point-New Madrid Floodway was very helpful; Messrs. W. M. Gay, J. A. Conway, S. B. Price, J. S. Sullivan, and W. Washington, who performed most of the field work; and Ms. Elizabeth Klein, who assisted in the artwork and assembled the report draft.

The U. S. Army Engineer District, Vicksburg, provided valuable assistance in meeting the test schedule by furnishing a drill rig and crew and by the loan of pumps for the model operation.

The study was under the general supervision of Mr. L. F. Ingram, Chief, Explosive Effects Division, SL, and Mr. B. Mather, Chief, SL.

Commanders and Directors of WES during the conduct of the study and the preparation and publication of this report were COL J. L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

A

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
calories (assumed 15°C)* per gram	4.186	joules per kilogram
cubic feet	0.02832	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
pounds (force)	4.448	newtons
pounds (force) per cubic foot	157.1	newtons per cubic metre
pounds (mass)	0.4536	kilograms

* Actually not identified by manufacturers (Table 1). The calorie shown here is in common usage in the U. S. The differences in caloric measurements are insignificant to this report.

BIRDS POINT-NEW MADRID FLOODWAY

EMERGENCY OPERATION

EXPLOSIVE DESIGN SUMMARY

PART I: INTRODUCTION

Purpose

1. Since 13 March 1979, the U. S. Army Engineer Waterways Experiment Station (WES) has participated in the development of an explosive design for emergency operation of the Birds Point-New Madrid (BP-NM) Floodway near Cairo, Illinois. This report summarizes WES research and recommendations concerning this design.

Background

2. Construction of the BP-NM Floodway was recommended by the Office, Chief of Engineers, in December 1927 and authorized in the Flood Control Act of May 1928. The "setback levee," which forms the western limit of the floodway, was completed in 1932, but the grade (elevation) reductions that were to form the "fuse plugs" of the old, frontline levee by allowing overtopping of floodwaters were delayed. Consequently, the flood of January-February 1937 necessitated emergency demolition of portions of the frontline levee, revealing serious technical, logistical, and political problems in floodway operation. Through the years, economic development in the floodway, compared with Cairo, has exacerbated the political problem.

3. The BP-NM Floodway lies within the geographical responsibility of the U. S. Army Engineer District, Memphis (MD). Public Law 84-99 currently governs emergency operation of the Floodway, placing this responsibility upon the President of the Mississippi River Commission (MRC). The frontline levee has been strengthened and increased in height, and the concept now is that emergency operation will be by last-minute demolition

to avoid intolerable conditions at Cairo. This philosophy virtually rules out all other means of breaching the frontline levee except explosives.

4. WES has participated in several studies regarding BP-NM. Two of these were hydraulic model investigations (WES 1949 and 1957). More recently, concern has shifted to explosive design aspects of the floodway. During the flood of 1973, WES advised on a continuous, informal basis regarding explosive emplacement design. Although there is no formal documentation of this advice, certain portions apparently survive in MD Regulation 500-1-1, Appendix R, governing floodway operation (Memphis District 1978).

5. The WES concern over the feasibility of MD plans for an explosive breaching of the frontline levee prompted letters in June 1973* and January 1974** from the Director, WES, to the Memphis District Engineer that suggested a study of large, preemplaced charges in the levee. The Memphis District responded affirmatively in February 1974, and in November 1975 WES submitted an operation plan calling for preemplacement of 472 containers designed to be filled with 1400 lb† each of ammonium nitrate slurry during an emergency (WES 1975). This plan attempted to deal with the considerable engineering and logistical problems surrounding such an operation, but not the political problems. No response was made to this plan, although there was another high-water "scare" in the spring of 1974.

6. In December 1977, WES was again called to an MRC/MD meeting on the development of an emergency operation plan for BP-NM. It was at this time that the possible use of a new slurry,†† which could be

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* Letter from Director, U. S. Army Engineer Waterways Experment Station, CE, to District Engineer, U. S. Army Engineer District, Memphis, Tenn., Subject: Emergency Opening of the New Madrid Floodway, 12 Jun 1973.

** Letter from Director, U. S. Army Engineer Waterways Experiment Station, CE, to District Engineer, U. S. Army Engineer District, Memphis, Tenn., Subject: Removal of New Madrid Fuse Plug Levee, 28 Jan 74.

† A table of factors for converting Inch-Pound units of measurement to metric (SI) units is given on page 4.

†† Intermountain Research and Engineering Company, Inc., (IRECO) Dense Blasting Agent (DBA) 105P (pumpable).

preemplaced in pipes, was first broached. Following this (16 August 1978), WES formally agreed to furnish qualified blasters to MD to implement the existing explosives plan.*

7. On 13 March 1979, WES was invited to send a representative to MD to discuss changes to the emergency operation plan. The need for changes had been brought out in an earlier briefing of the President, MRC, and a subsequent briefing was being hurriedly staffed. In the preliminary discussions, the District Engineer, MD, decided to adopt an operation plan format and to address the total problem--technical, logistical, and political. WES was asked to draft Annex F (Explosive Plan), which was initially limited to a rather narrow range of responsibilities concerning supervision of explosives placement, arming, and firing (or recovery of explosives in the event that demolition was not carried through). The subsequent briefing on 23 March 1979 and discussion of the plan** brought to light several serious questions regarding explosive breaching, and WES was requested by MRC to propose model tests that would resolve these questions.† The WES response called for a three-phase (later four-phase) test of detonating cord layout design, full-scale explosive loading of boreholes, and a scale model. The fourth and final phase was the selection of longitudinal spacing of boreholes after all other parameters had been established by experiment or logistical constraints.

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* Letter from District Engineer, U. S. Army Engineer District, Memphis, to Director, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., Subject: Agreement for Services by WES Personnel, 2 Aug 78.

** Memorandum for Record, U. S. Army Engineer Waterways Experiment Sta-Station, CE, Vicksburg, Miss., Subject: Official Visit to Memphis Engineer District, 23 Mar 1979, dated 27 Mar 79.

† Letter from Secretary, Mississippi River Commission, to Director, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., Subject: Proposed Explosive Testing for Birds Point-New Madrid Floodway, 29 Mar 79.

PART II: EXPERIMENTAL PROCEDURES AND RESULTS

Detonating Cord Layout (Phase I)

8. As finally approved, Annex F (Explosive Plan) to the MD Plan of Operation* provided for a total of 3,066 boreholes in two disconnected levee lengths (crevasses) totaling 17,370 ft. A "ring main" of primacord was to be laid for each crevasse, with details of borehole hook-ups as shown in Figure 1. Except for a dual cross-connection at each transverse row, this was no change from the previous plan (Memphis District, 1978). The new plan, however, specified initiation by an exploding bridge-wire (EBW) detonator system.

9. In order to verify the adequacy of the proposed layout, WES conducted four tests at the Big Black Test Site (BBTS) - one with an abbreviated (but otherwise complete) layout, and two additional abbreviated layouts including various degrees of degradation to test redundancy (Figure 2). The more severe of these included 11 breaks and an assumed cap misfire. A final "reduced redundancy" test contained only one cross-connection at each transverse row. Complete detonation occurred in all cases.

Full-Scale Borehole Loading (Phase II)

10. This phase began with a six-charge array fired 9 April 1979 at BBTS and attended by several MRC observers. Originally, this test was intended to duplicate as closely as possible the geometry, explosive loading, boosting, stemming (with water), and detonating cord layout and initiation envisioned in the operation plan (Figure 3). The explosive designated for use in the plan was at this time DuPont de Nemour's "Pourvex";** unfortunately, it could not be made available to meet the

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* Memo for Record, op. cit.

** Commercial name. Table 1 contains basic information on this and other commercial slurries used or considered for use in these tests.

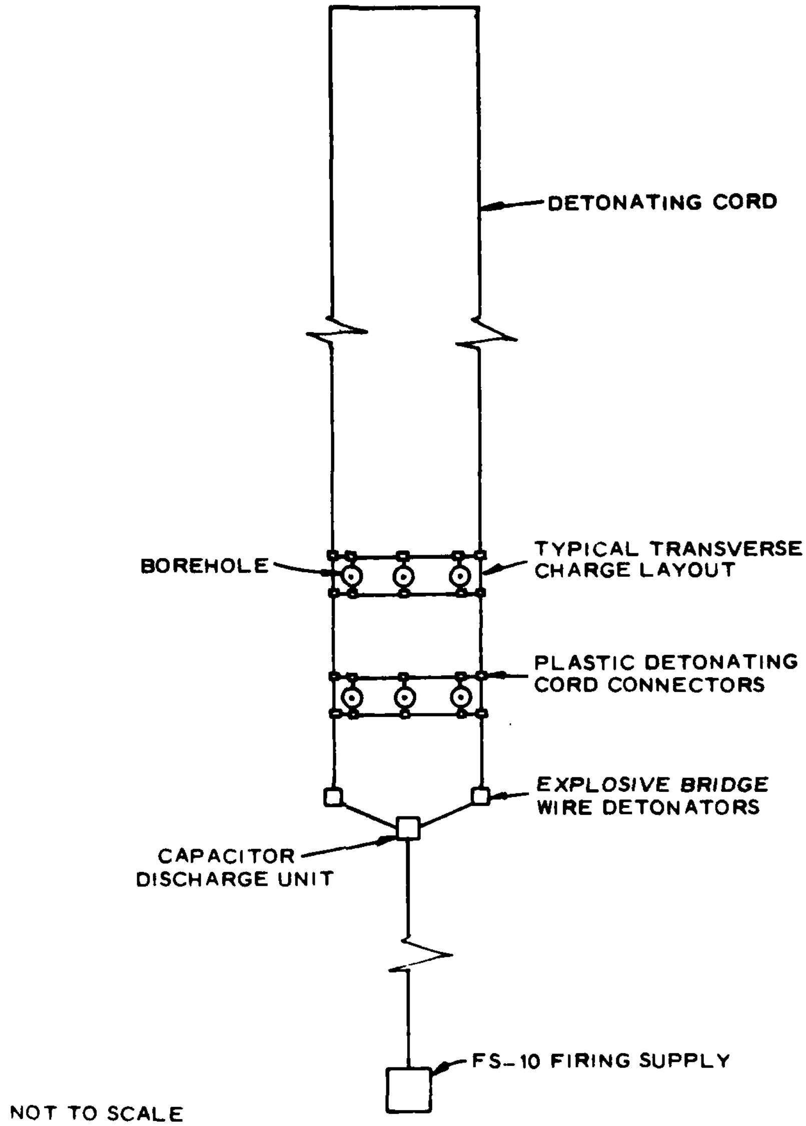

Figure 1. Detonating cord layout, 50-grain primacord

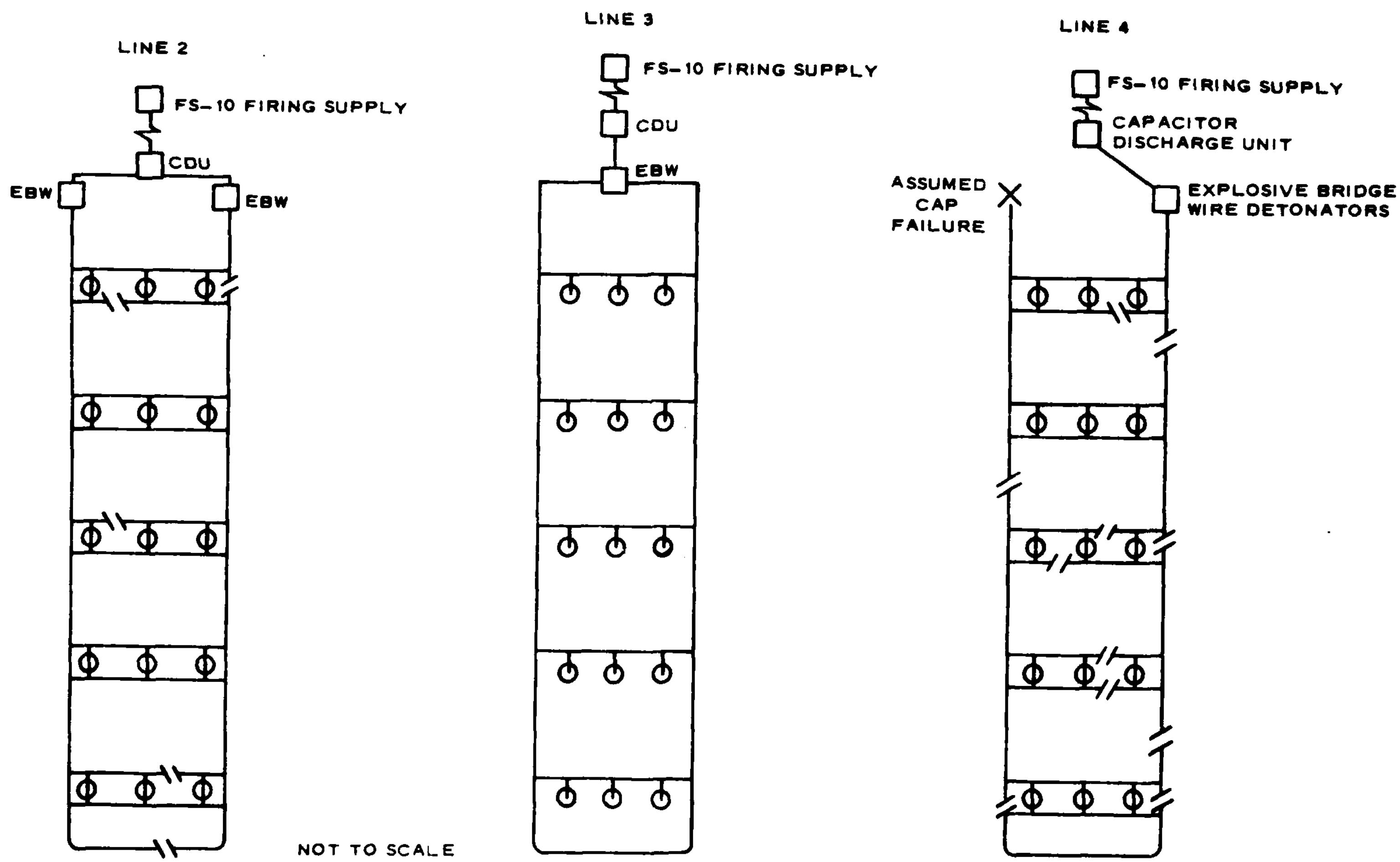

Figure 2. Degraded detonating cord layout

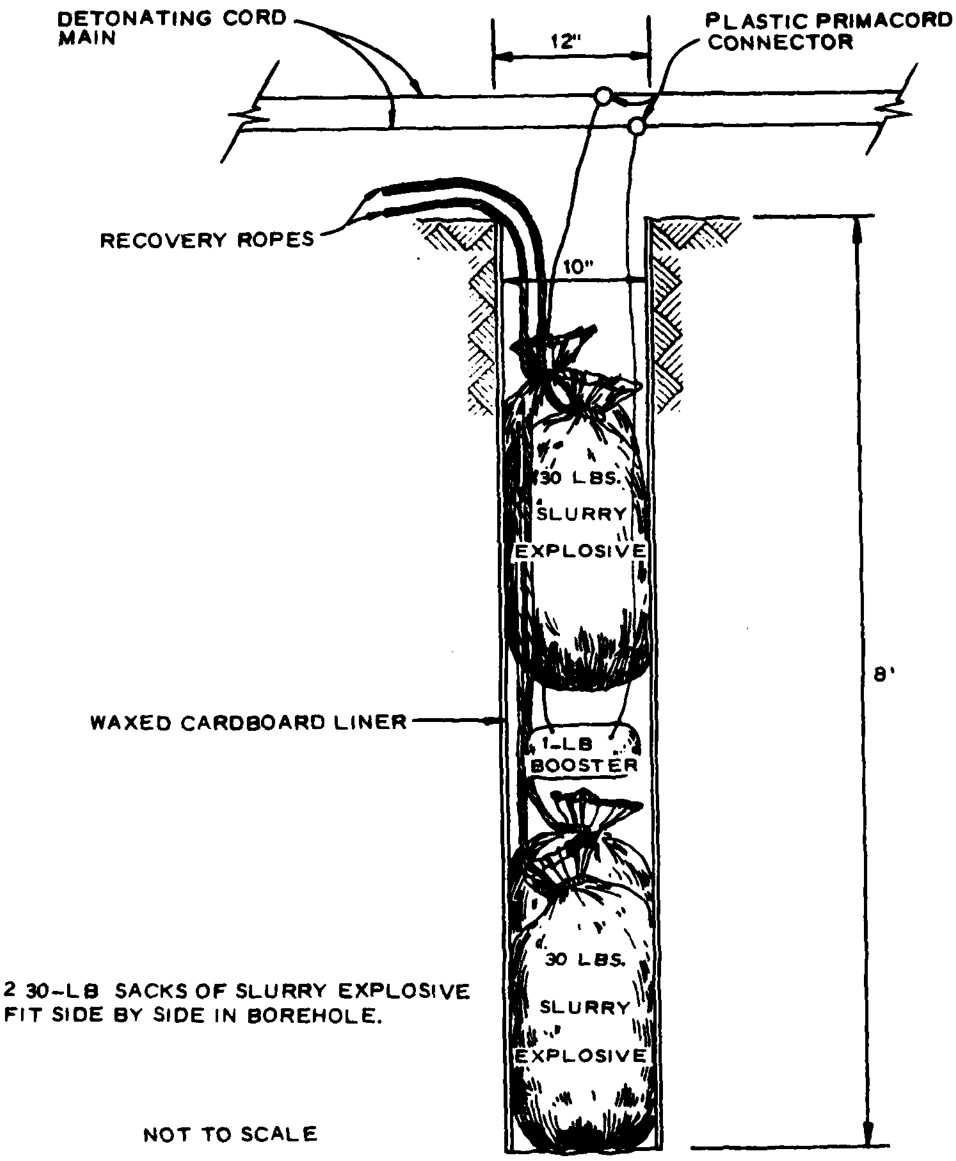

Figure 3. Typical borehole loading

Table 1

Basic Properties of Explosives

Manufac-urer/Name	Specific Weight lb/ft^3	Total Energy cal/g	Aluminized	Detonation Velocity ft/sec	Classifi-cation (for shipping)	Approxi-mate Cost* dollar/lb
TNT**	97	1100	No	23,000	HE†	1.00
C-4**	99	1430	No	26,400	HE	3.10
IRECO/ DBA 22M	87	1920	Yes	13,000	BA††	0.55
IRECO/ DBA 105P	97	2200	Yes	13,000	BA	0.65
ESC/ MS80-20	75	1320	Yes	15,000	BA	0.30
Hercules/ Flogel	84	870	Yes	18,000	BA	0.42
DuPont/ Tovex "extra"	83	730	No	20,000	BA	0.47
DuPont/ Pourvex	83	680	No	19,700	BA	0.40
Hercules/ Gel Power OP	81	715	No	18,000	BA	0.40

Note: Properties vary with methods of manufacture.
* Quoted in April 1979.
** Standard military explosive produced by military services.
† High explosive.
†† Blasting agent - insensitive to No. 8 blasting cap.

stringent time requirements imposed by MRC, and a substitute was furnished by MD - Hercules "Gel Power OP". As shown in Table 1, this is roughly equivalent to Pourvex. Figure 4 shows the layout and results of the Phase II test.

11. The Phase II shot demonstrated that the low-energy slurry designated in the operation plan was inadequate, and served to open the door to discussions concerning explosive selection and layout and emplacement geometry. As a result of these discussions, Phase II was expanded to include "side-by-side" tests of leading candidate slurries of major explosive manufacturers. Telephone inquiries were made to DuPont, Hercules, Intermountain Research and Engineering Co. (IRECO), Engineering Sciences Consultants (ESC) and Atlas. Atlas opted not to compete, but each of the others recommended a candidate explosive which was purchased and tested, along with the plastic military explosive C-4, which was used as a "baseline" explosive. Three shots were fired for each explosive, thus providing a "significant" test, i.e., providing a high assurance that results based on a one-time extreme performance would be avoided. Since the earth-moving capabilities* of the explosives were in doubt, the three shots were fired in boreholes 6, 8, and 10 ft deep to ensure a bracket of optimum burial.** As originally conceived, Phase II was completed in July 1979. Close examination, however, raised some doubt as to whether the above-mentioned depths provided an optimum DOB for the leading candidate, IRECO's DBA 22M. Consequently, when more of this explosive became available later in the testing program, two additional shots were fired in August to further refine its cratering capabilities curves. The craters resulting from the Phase II tests are profiled in Figures 5-10, and cratering capability graphs are in Figures 11 and 12. Phase II ended with a recommendation (adopted) that DBA 22M be selected as the primary

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* Earth-moving capability is thought to depend primarily upon energy, gas formation, and detonation velocity; it probably varies in some inverse fashion with the last-named characteristic. Unfortunately, the exact nature of earth-moving by explosives is not well understood.

** Optimum depth of burial (DOB) - the depth resulting in the largest apparent crater volume.

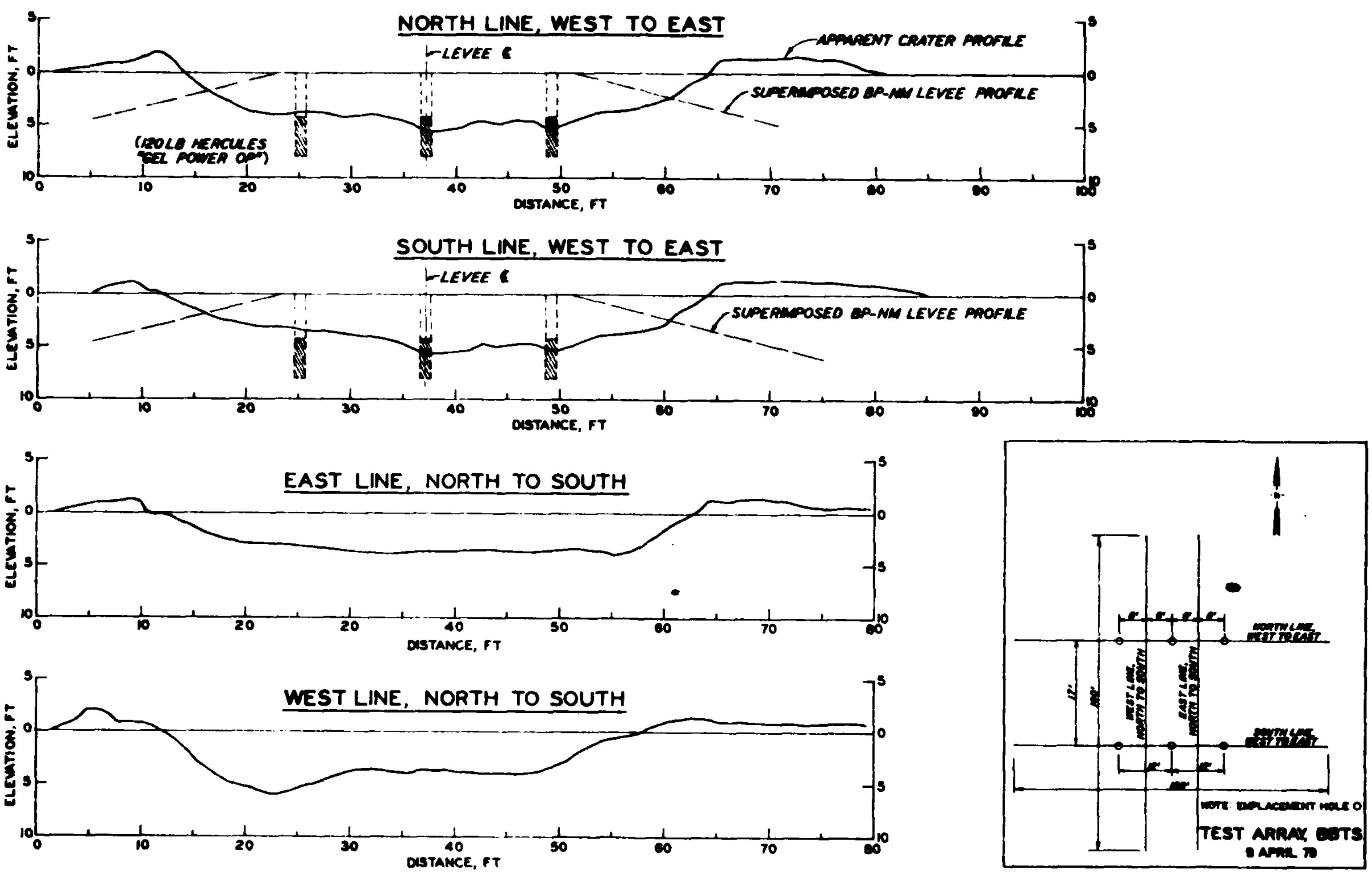

Figure 4. Phase II test layout

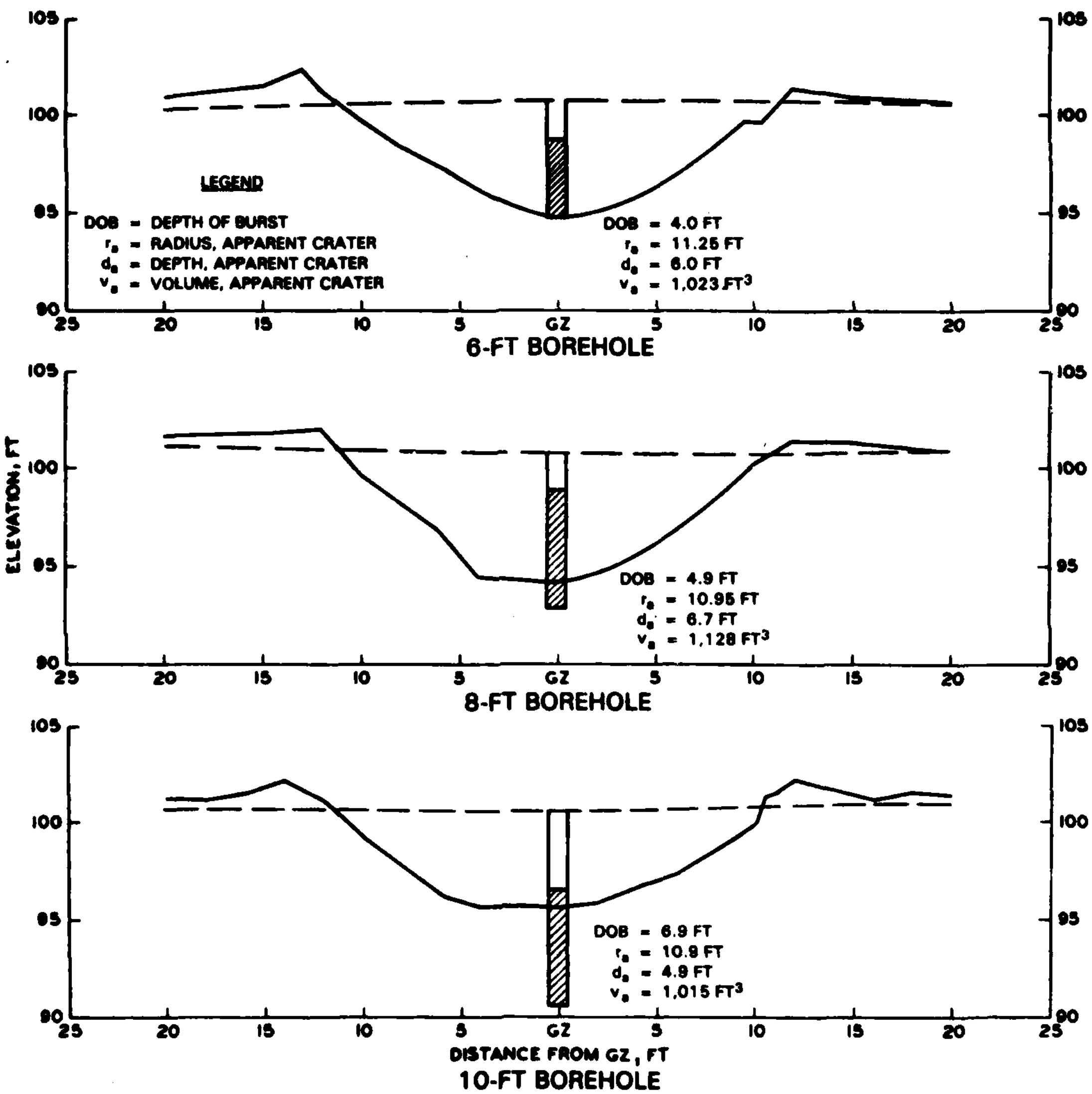

Figure 5. Phase II apparent crater profiles, 120-lb Dupont Tovex charges

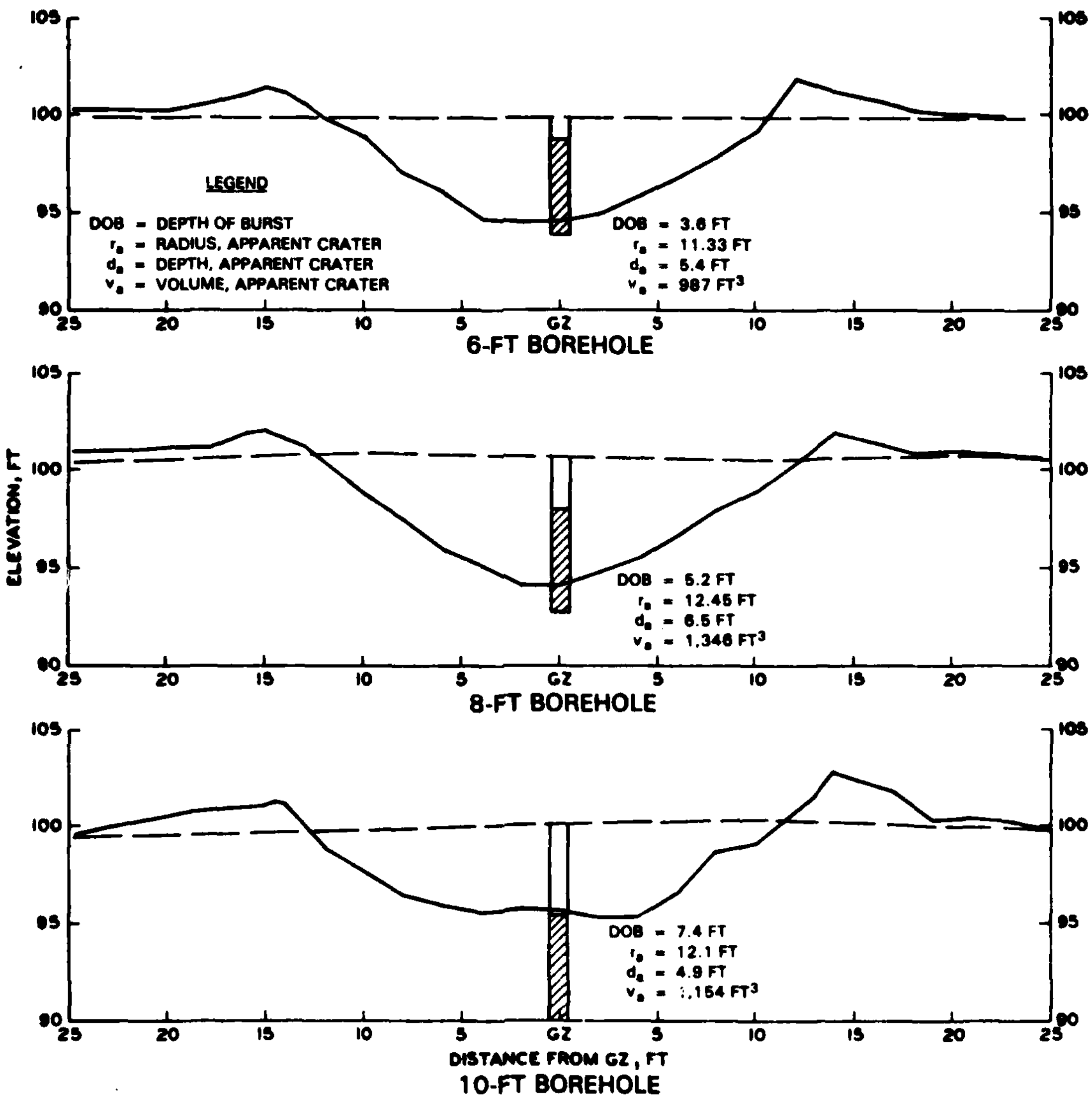

Figure 6. Phase II apparent crater profiles, 120-lb Hercules Flogel charges

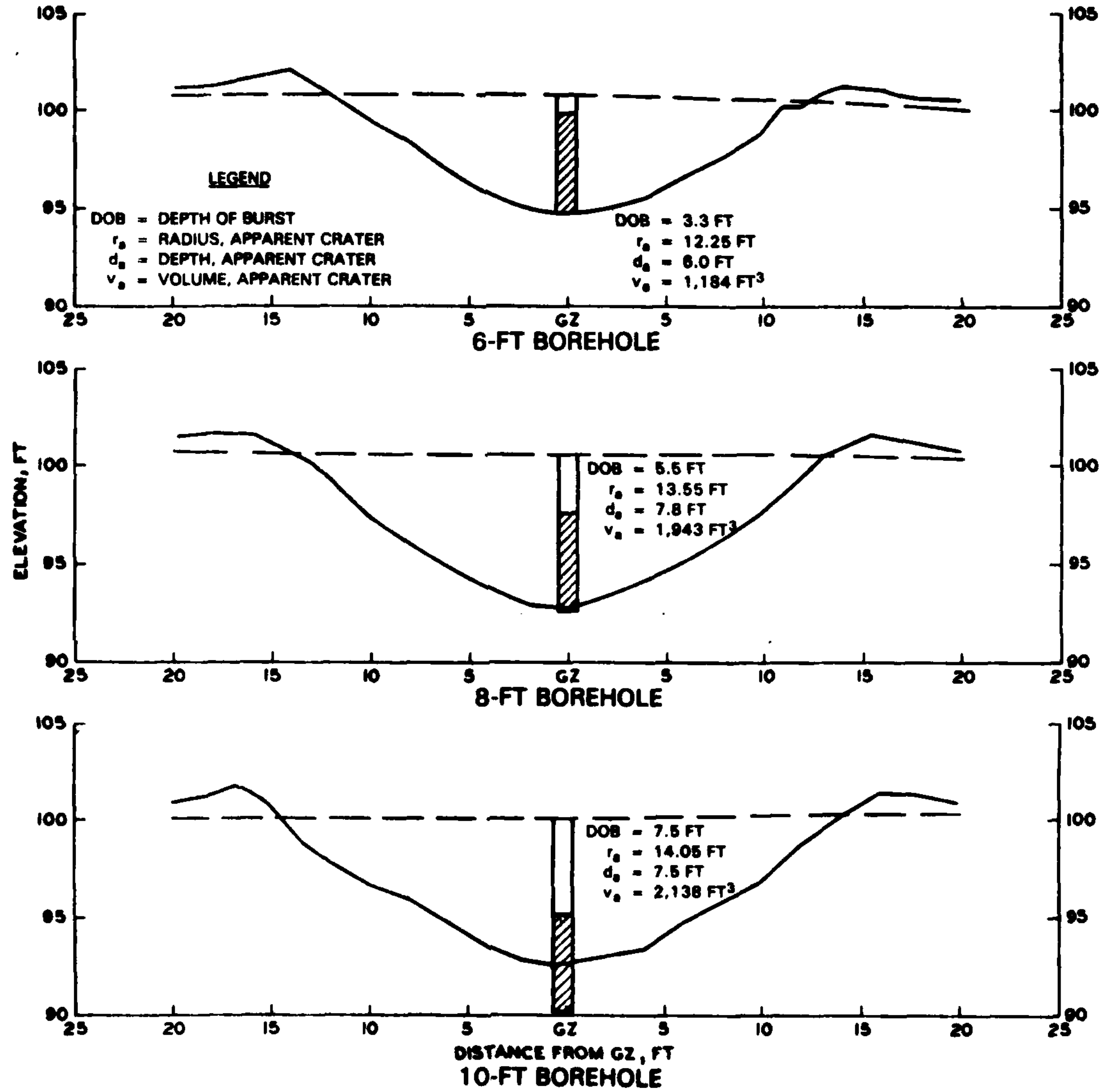

Figure 7. Phase II apparent crater profiles, 120-lb ESC MS-80-20 charges

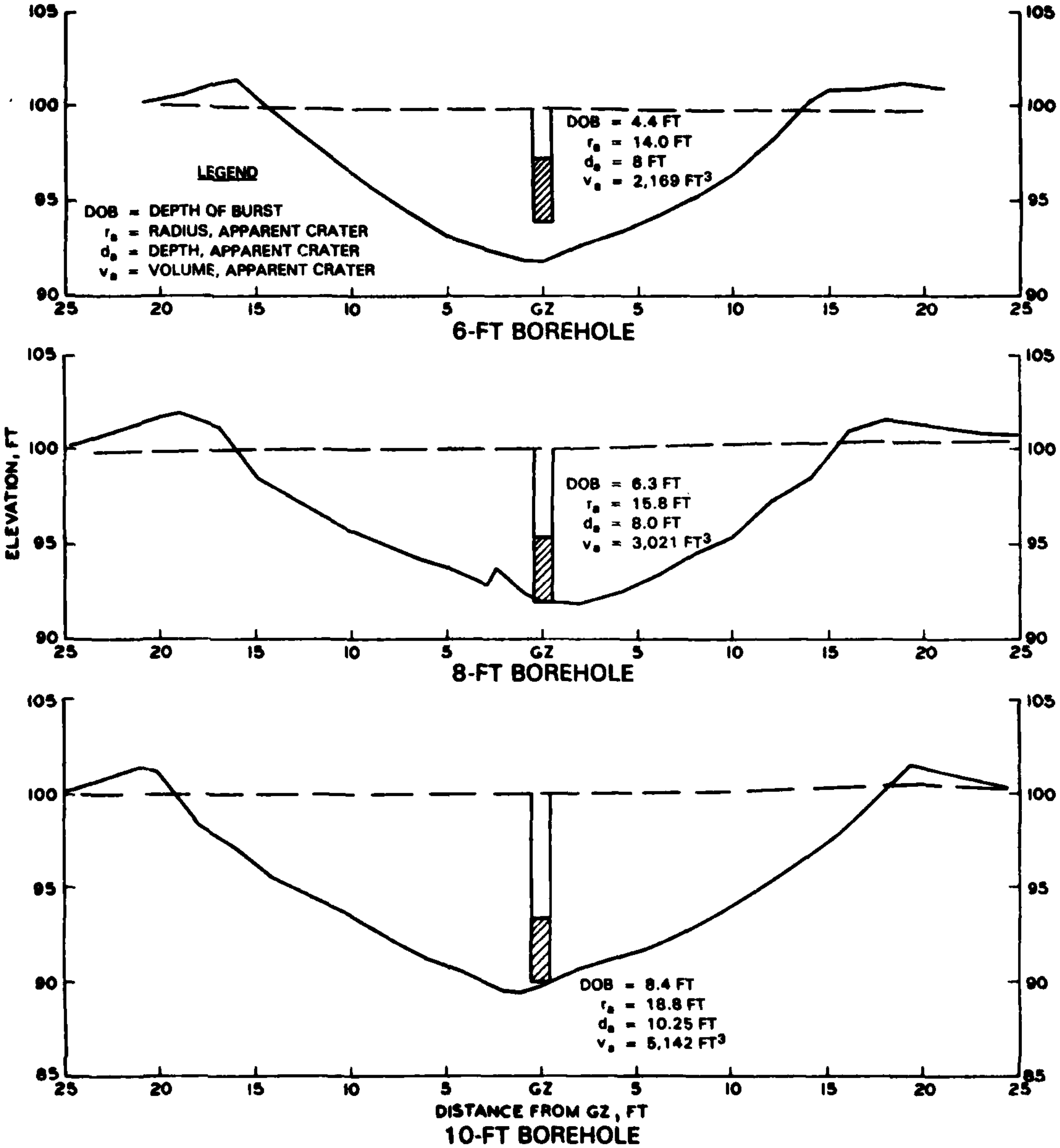

Figure 8. Phase II apparent crater profiles, 120-lb IRECO DBA 22M charges

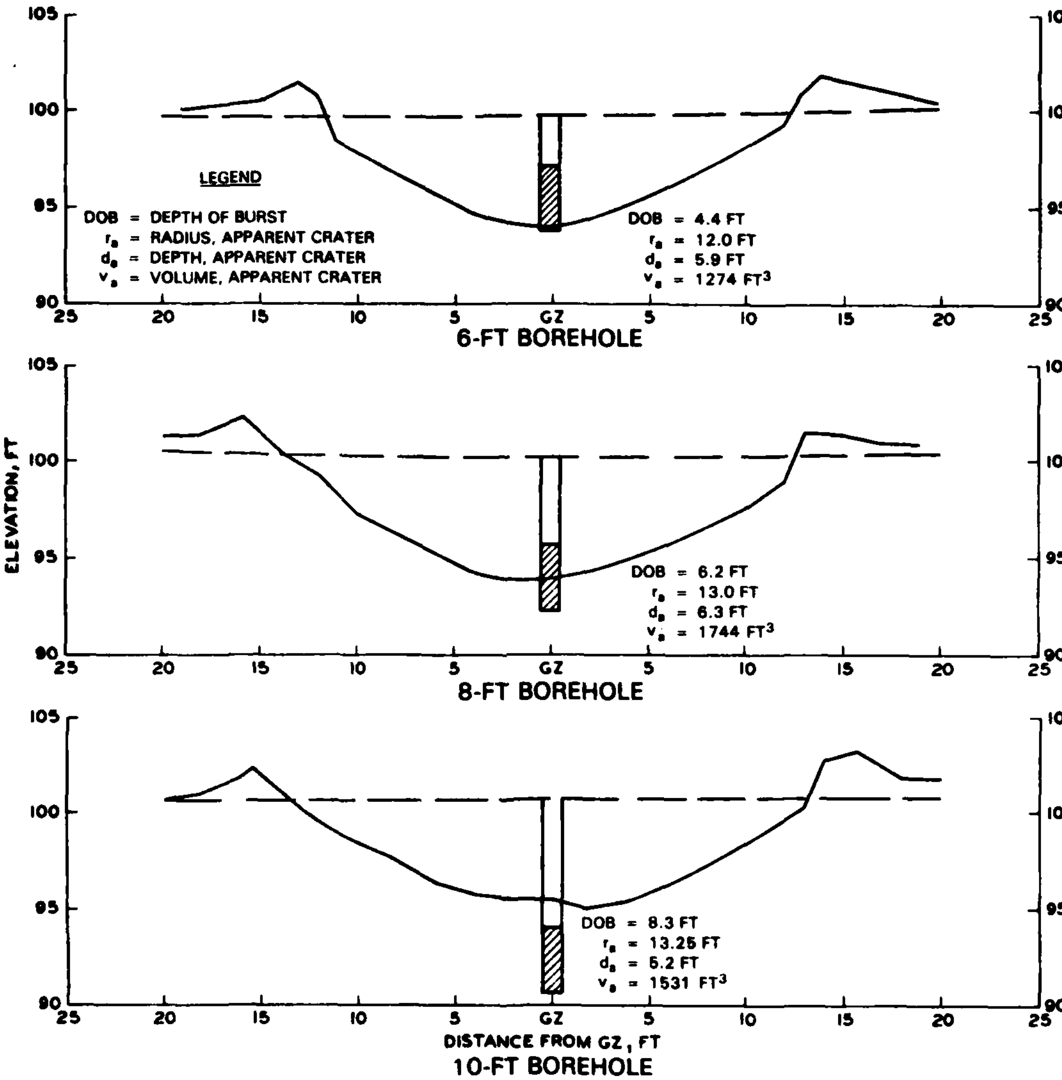

Figure 9. Phase II apparent crater profiles, 120-lb C-4 charges

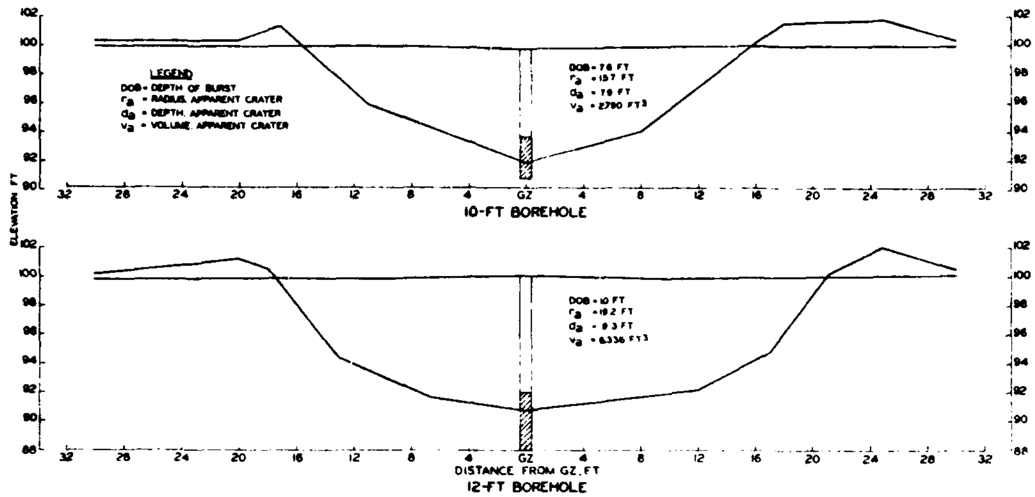

Figure 10. Phase II additional apparent crater profiles, 120-lb IRECO DBA 22M charges

explosive for use in the frontline levee breaching, and that it be fired in boreholes approximately 10 ft deep.

Scale Model (Phase III)

12. It was the suggestion of a scale model that prompted MRC's invitation for the current study of the BP-NM problem. The use of an existing basin at the BBTS filled to represent some river stage, and with a berm shaped to represent the frontline levee, seemed an attractive, economical approach to a difficult problem. The original WES proposal was chronologically structured so that the prototype charge and detonating cord design could be established and fired in the model. However, when Phase II was expanded (and prolonged), work went ahead on Phase III, again because of MRC's time limitations, and C-4 was selected for the model charge. There were two good reasons for this:

a. C-4 is a standard, dependable explosive, with earth-moving properties considered comparable to TNT, the usual standard.

b. It is plastic and easily molded into the desired shape.

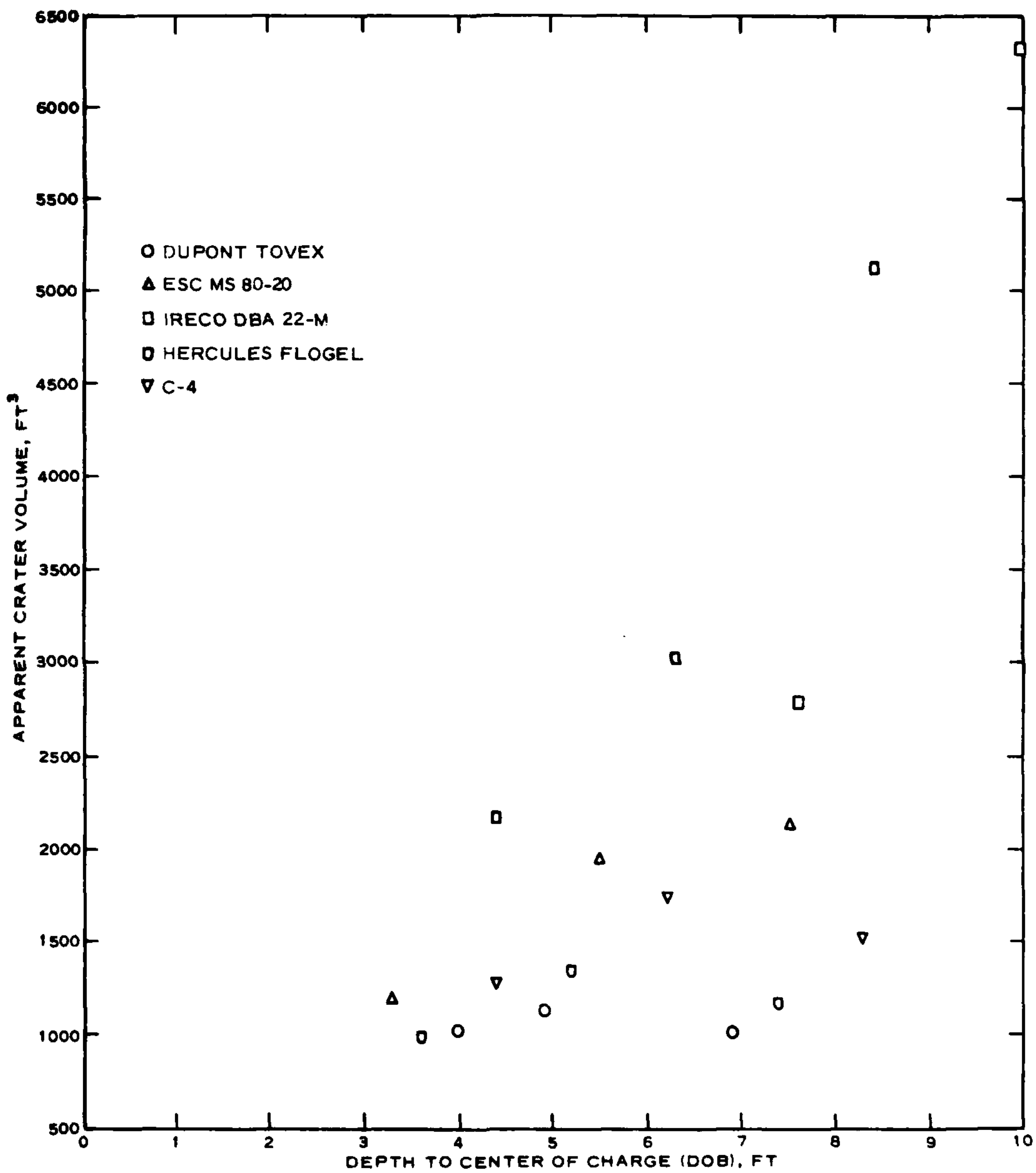

Figure 11. Apparent crater volumes versus depth of burial, 120-lb cylindrical charges

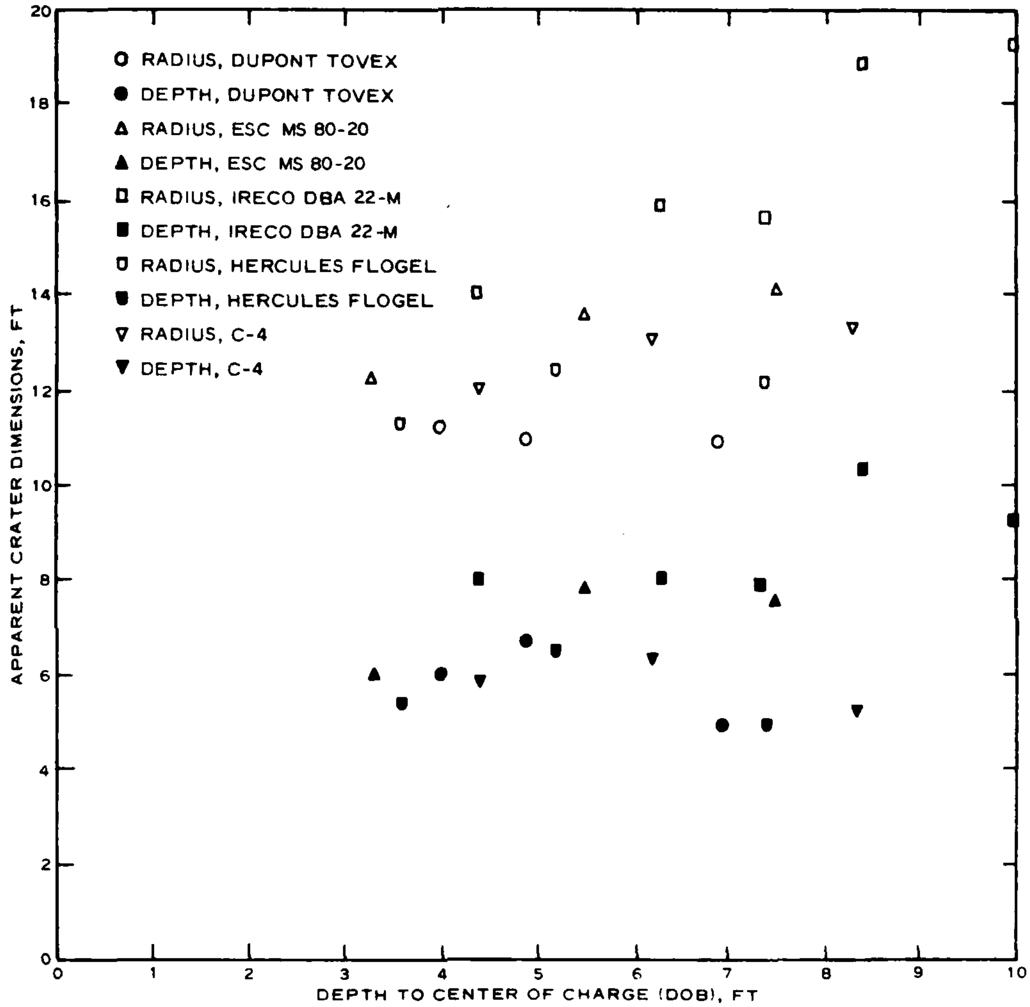

Figure 12. Apparent crater dimensions versus depth of burial, 120-lb cylindrical charges

Thus, the scale model was to answer some rather basic questions about the cratering behavior of the levee using a standard explosive and the existing emplacement plan; it was felt that, if necessary, a second model could be fired later, after final charge selection.

Scaling Laws

13. Basically, it was envisioned that three sets of scaling "laws" would govern model/prototype relations:

- a. "Replica" scaling, in which model and prototype consist of the same materials, would govern the media (soil and water) in which the detonation occurred. Replica scaling ignores gravity. Obviously, the BBTS berm, composed of sand-silt-clay would only approximate the buckshot clay levee. Further, the C-4 would only approximate the selected slurry.
- b. Crater scaling would be governed by "mass" scaling, also known by various other names such as "Mach" and "Lampson," and sometimes simply as "cube-root" scaling. It, too, ignores gravity, while assuming that medium densities in the model and prototype are constant. Mass scaling has been found adequate for small model/prototype charge ratios.
- c. Any hydraulic phenomena, such as discharge over the breached levee, would be governed by Froude scaling, which equates dimensionless terms consisting of velocity, length, and gravity in the model and prototype. When gravity is the same in both, certain scale relations result.

Appendix A lists the major relations of each of the above.

14. The main consideration in the selection of the model scale was optimum use of one of the existing basins at the BBTS; the shallow-water basin was selected for this purpose. Comparison of its berm design with an updated cross section of the BP-NM front-line levee furnished by MRC (Figure 13) showed that a one-third scale model was about optimum, permitting construction of an adequate cross section by cutting of the existing, well-consolidated berm. This scale also appeared to offer an adequate charge size. Figure 14 is a model construction drawing, while Figure 15 contains photographs of the basin and the model under

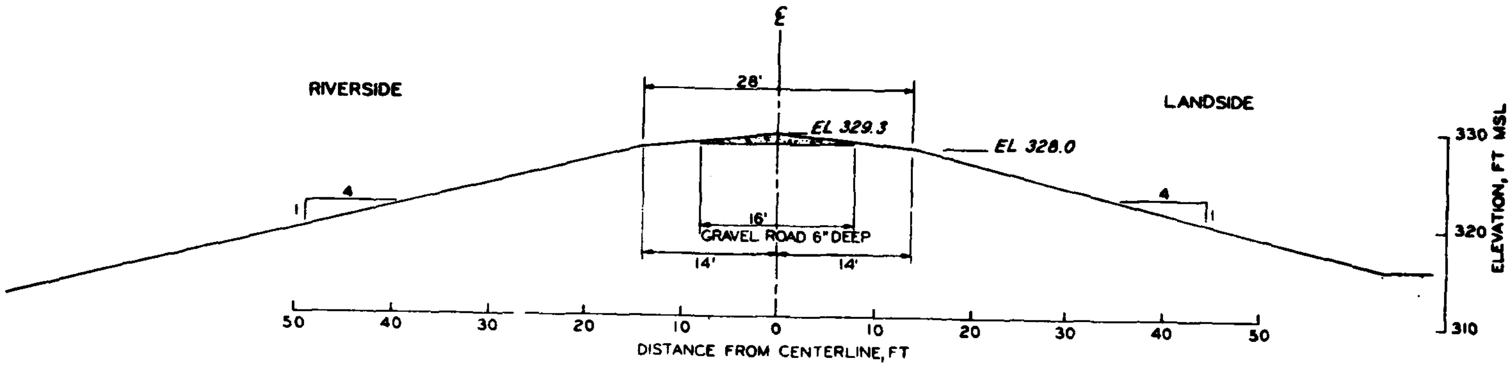

Figure 13. Cross section BP-NM levee, upper crevasse

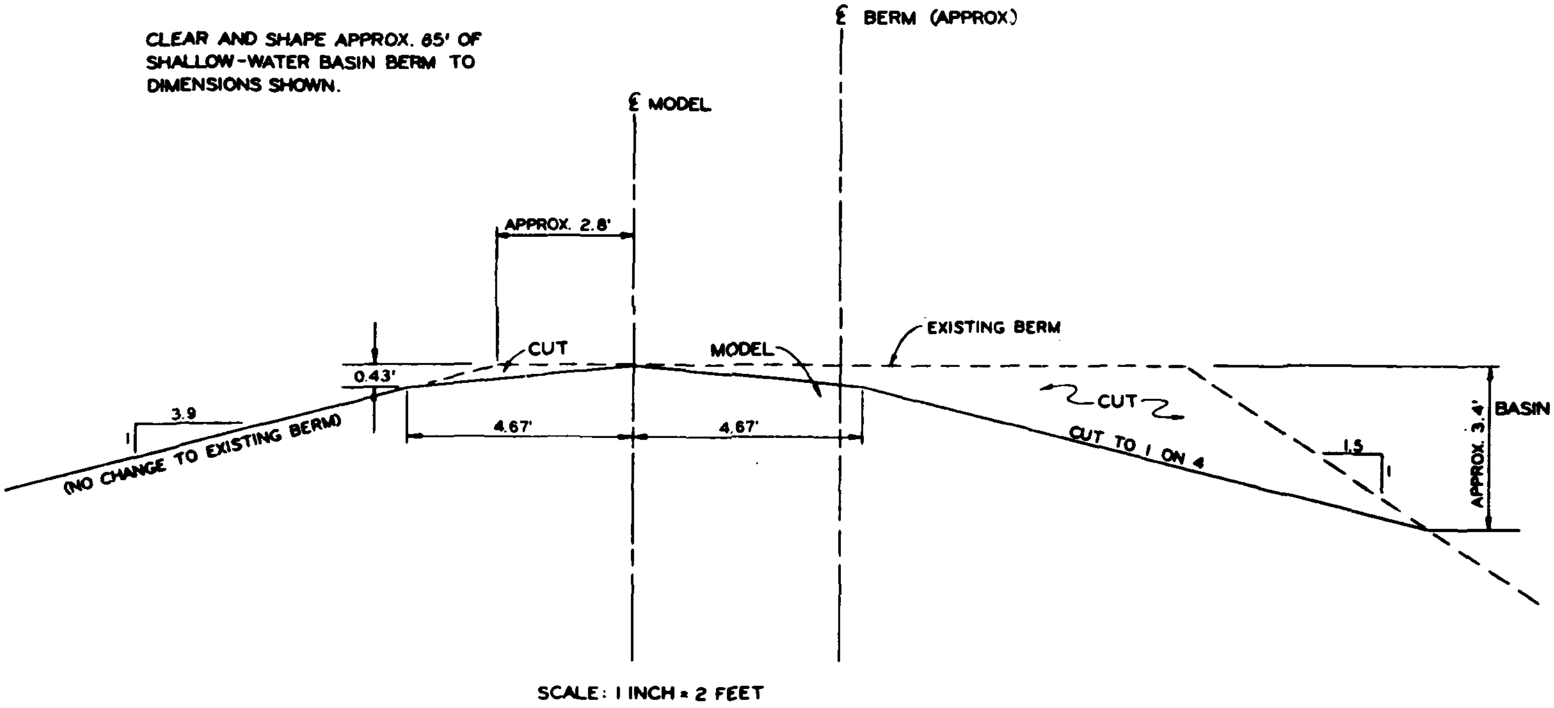

Figure 14. Typical cross section for construction of model levee

a. Site preparation

b. Placement of hole casing

Figure 15. Model construction (sheet 1 of 2)

c. Site completion

d. Staff gage

Figure 15 (sheet 2 of 2)

construction. A 30-charge array was designed (3 across the berm, 10 along the berm) which insured the adequate development of the ditching action to be expected in the prototype. All dimensions were scaled from the operation plan.

Model charge

15. Once the linear scale is established, model charge weight W_m may be determined as follows:

$$W_m = \left(n\, W_p^{1/3}\right)^3 \tag{1}$$

where

n = fractional model/prototype scale relation, e.g. $n = 1/3$ for one-third-scale model

W_p = prototype charge weight

For this model, where the prototype charge, according to the operation plan, was to consist of 120 lb of slurry plus a 1-lb booster (ignoring primacord),

$$W_m = \left[\frac{1}{3} \cdot (121)^{1/3}\right]^3 = 4.48 \text{ lb}$$

16. Construction of the model charge, to include its initiation, posed some problems, and several tests of single model charges were run to resolve these problems. A cardboard container was derived as a means to mold the C-4 to the proper dimensions, and it was decided to effect initiation by running strands of primacord lengthwise through the charge, knotted at the bottom. The density of the C-4 is appreciably greater than most slurries, resulting in a more compact charge with a lower effective DOB (if all other linear dimensions are faithfully scaled).

17. Selection of primacord was also a consideration: 50-grain* primacord is prescribed for the prototype and is known to reliably detonate C-4, but it seemed preferable to observe scaling as much as

* 50 grains of PETN explosive per linear foot. By strict scaling (Equation 1, paragraph 22), this would be less than 2 grains/ft in the model.

possible, and thus to use the smallest primacord feasible. There was available a quantity of 18-grain cord, which was used successfully to fire five of five model charges. Based on this, the 18-grain detonating cord was adopted as part of the model charge design. Later events were to cast doubt on this decision.

Hydraulic considerations

18. During model design, problems appeared in the BBTS pumping and filling system, which had laid unused for quite some time. The system was restored, but MRC in the meantime arranged for the use of several centrifugal, tractor-driven pumps* with which to fill the basin. In planning for the model detonation, it was decided to have two tractor-driven pumps in place and ready to operate in conjunction with the regular filling system so as to maintain (or attempt to maintain) the basin level for several minutes following the breach, thus allowing observations of discharge and scour. To this end, a rough calibration of the filling system was made, and photographic monitoring of a staff gage at the far end of the basin was prepared. This all came to naught when the detonation failed to breach the levee.

Results

19. The one-third-scale model was detonated 21 May 1979. Figure 16 shows this event, revealing a gap in the landside explosion plumes that is apparently caused by several adjacent charges either failing to detonate or detonating incompletely. The primacord layout functioned without difficulty. Postshot excavation and survey resulted in the recovery of approximately 18 lb of C-4, the equivalent of four complete charges. This material was found either near the landside row in the crater or in the ejecta field north (landside) of the model levee. There is a possibility that additional, unexploded C-4 was deposited in the basin (photography is inconclusive), but it seems clear that a group of adjacent, landside charges was the main problem. Examination of the recovered explosive further indicates that the 18-grain primacord failed to transmit sufficient shock to detonate the C-4. The fact that this

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* Borrowed from Vicksburg District.

Figure 16. Phase III shot. Note gap (arrow) in row, indicating undetonated charges

failure occurred in adjacent charges (rather than randomly) has not been explained.

20. Figure 17 shows the crater immediately after detonation, while Figure 18 is a composite of several views after drawdown of the basin. As can be seen, there was virtually no flow over the model levee. The crater clearly shows the irregularities caused by detonation failures. Figures 19 and 20 are longitudinal and transverse profiles of the crater. Points on the true crater are the best estimates that could be made without the aid of some preemplaced means of distinguishing dissociated from undissociated soil. During crater excavation, special attention was given to the landside charge row and also to the rather suspicious humps on the basin side of the crater; except for the landside row, however, no unexploded charges or charge locations were identified. Irregularities such as this may be the result of nonsimultaneity of detonation, which is to be expected in a series-connected charge array initiated by primacord.

a. Postshot safety check

b. Close-up of east end of levee

Figure 17. Crater immediately after detonation

Figure 18. Composite of crater after basin drawdown

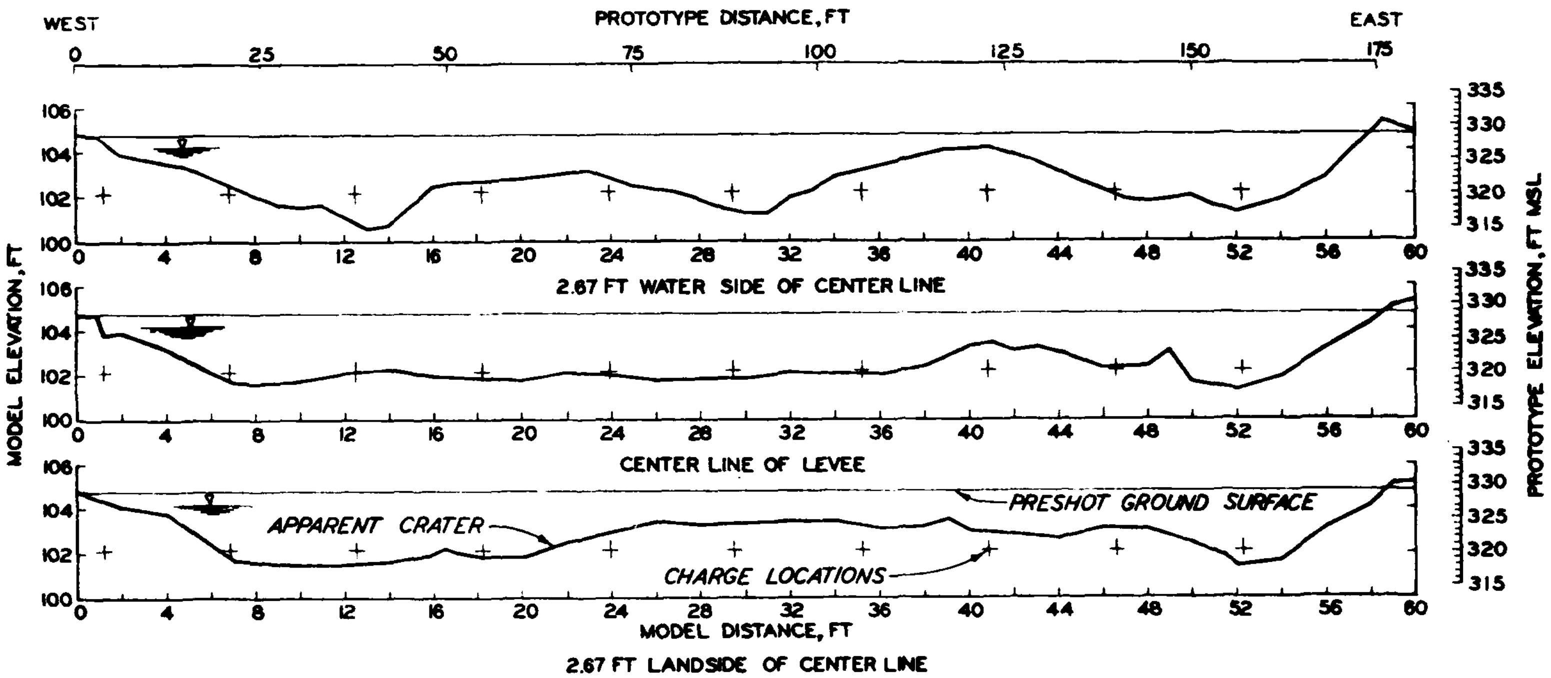

Figure 19. Apparent crater longitudinal profiles, model levee shot

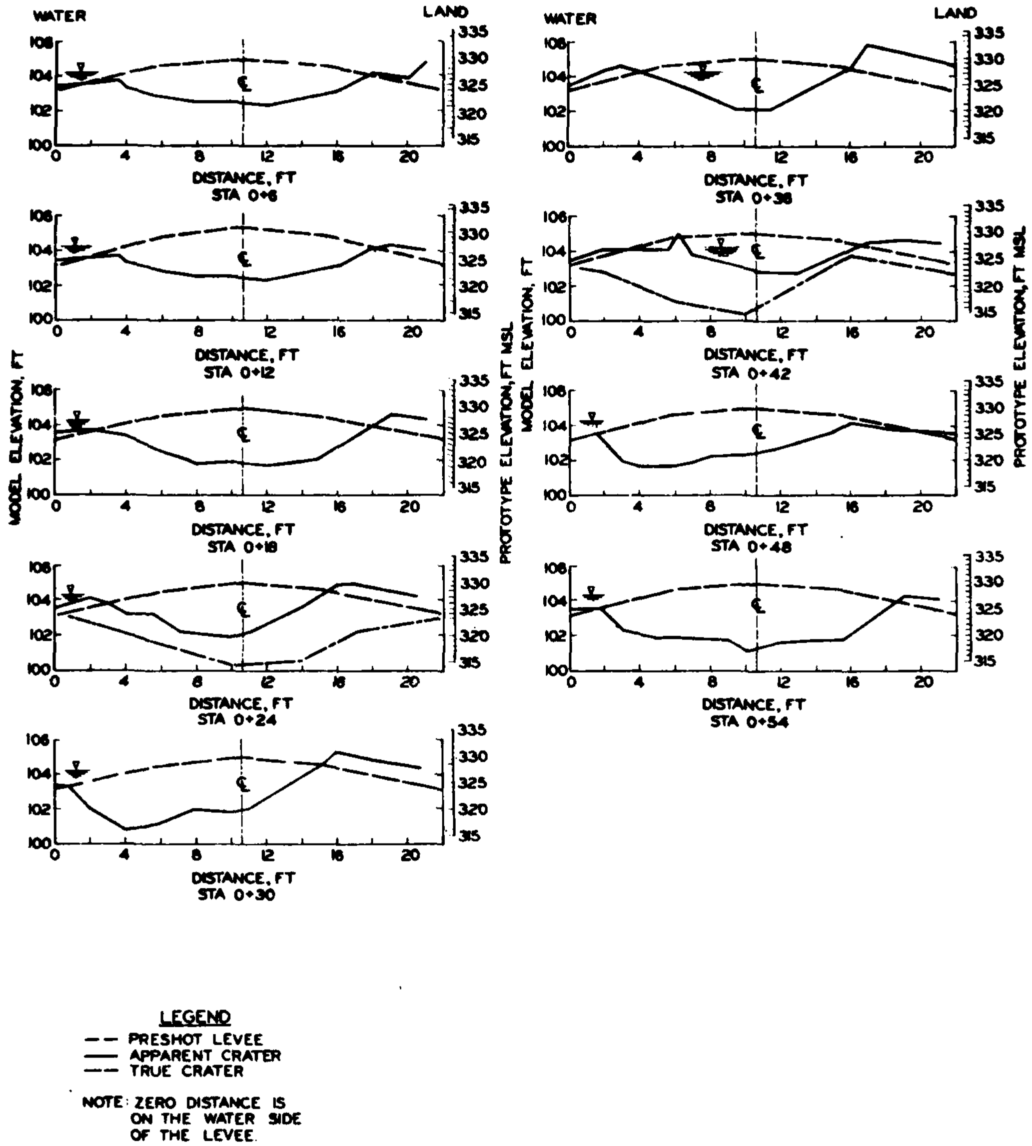

Figure 20. Cross section crater profiles, model levee shot

21. In general, this test pointed up problems in the modeling procedures, but it also served to demonstrate that the explosive plan contained in the operation plan was inadequate, a fact already suspected from the 9 April Phase II event.

Longitudinal Spacing (Phase IV)

Design rationale

22. By the time that the expanded Phase II tests had been completed and a slurry selection had been made, earlier plans for a follow-on model test did not appear as attractive as they once did. MRC had imposed a new deadline which seemed to preclude adequate model charge design; preliminary tests of a model DBA 22M charge hinted at a degradation in slurry performance, possibly due to the approach to a critical (for high-order detonation) charge diameter. At a 26 June meeting, WES agreed to submit plans and cost for modeling two additional explosive plans; but in a 13 July letter, WES recommended instead two six-charge, full-scale arrays of the DBA 22M, similar to the 9 April shot. After funding for this was received, MRC notified WES of an additional constraint (maximum 10-ft borehole depth, limiting charge size to about 120 lb) and an additional requirement (minimum 8-ft crater depth in first 24 hours).* Earlier interest in exact duplication of river conditions, levee moisture content, and early scour had waned. On 27 August another meeting was held, in which it was recognized that only one major design parameter was seriously in need of further testing--that of longitudinal spacing. Full-scale tests were not necessary for this purpose (nor, because of space and airblast limitations, even desirable); a scale model would suffice. The simplest course seemed to be a model keyed to the 30-lb DBA 22M package. By Equation 1,

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* Never precisely defined as to where measured. It had been generally accepted that the vertical borehole design would unavoidably leave a shallow crater edge on both the riverside and the landside of the crater, hopefully to be removed by erosion.

$$30 \text{ lb} = \left[n \ (120 \text{ lb})^{1/3}\right]^3$$

$$n = \sqrt[3]{\frac{30}{120}} = 0.63$$

23. The predicted apparent crater radius r_a for a 120-lb DBA 22M charge in a 10-ft-deep borehole is 16-17 ft in the buckshot clay of the frontline levee (about 90 percent of the BBTS crater) (WES 1961). In order to take advantage of row-charge enhancement (synergistic increase in crater size due to proximity of adjacent charges), a longitudinal spacing $\approx 1 \ r_a$ was under consideration. However, there was little experience in row-charge enhancement in BBTS soil, and no experience in this phenomenon regarding simultaneous detonations of multiple rows. In order to expedite testing and to bracket the $1 \ r_a$ spacing, two test 15-charge arrays of 14- and 18-ft (prototype) longitudinal charge spacings were planned, both with 14-ft (prototype) transverse spacings. Figure 21 illustrates the spacing layouts.

Results

24. Both arrays were fired 12 September 1979; Figures 22 and 23 contain crater (ditch) profiles. The 14-ft spacing generally met the 8-ft depth requirement, except, of course, at the riverside and landside extremes, where depth was about 3.5 ft. An elongated mound occurred near the center of the ditch, possibly consisting of fallback material (which would be expected to scour readily), or possibly by rebound of in situ material due to the underlying water table. If the latter, it would not be expected in the prototype.

25. The 18-ft spacing produced a crater slightly shallower than the 8-ft (within 24 hours) requirement. For both ditches, it is suspected that enhancement exceeds that which would occur in the prototype, since crater radii are larger at the BBTS. In view of this and the uncertainty of scour,* it was recommended that the 18-ft spacing be

* Limited observations on another study indicate that compacted clay is highly resistant to scour.

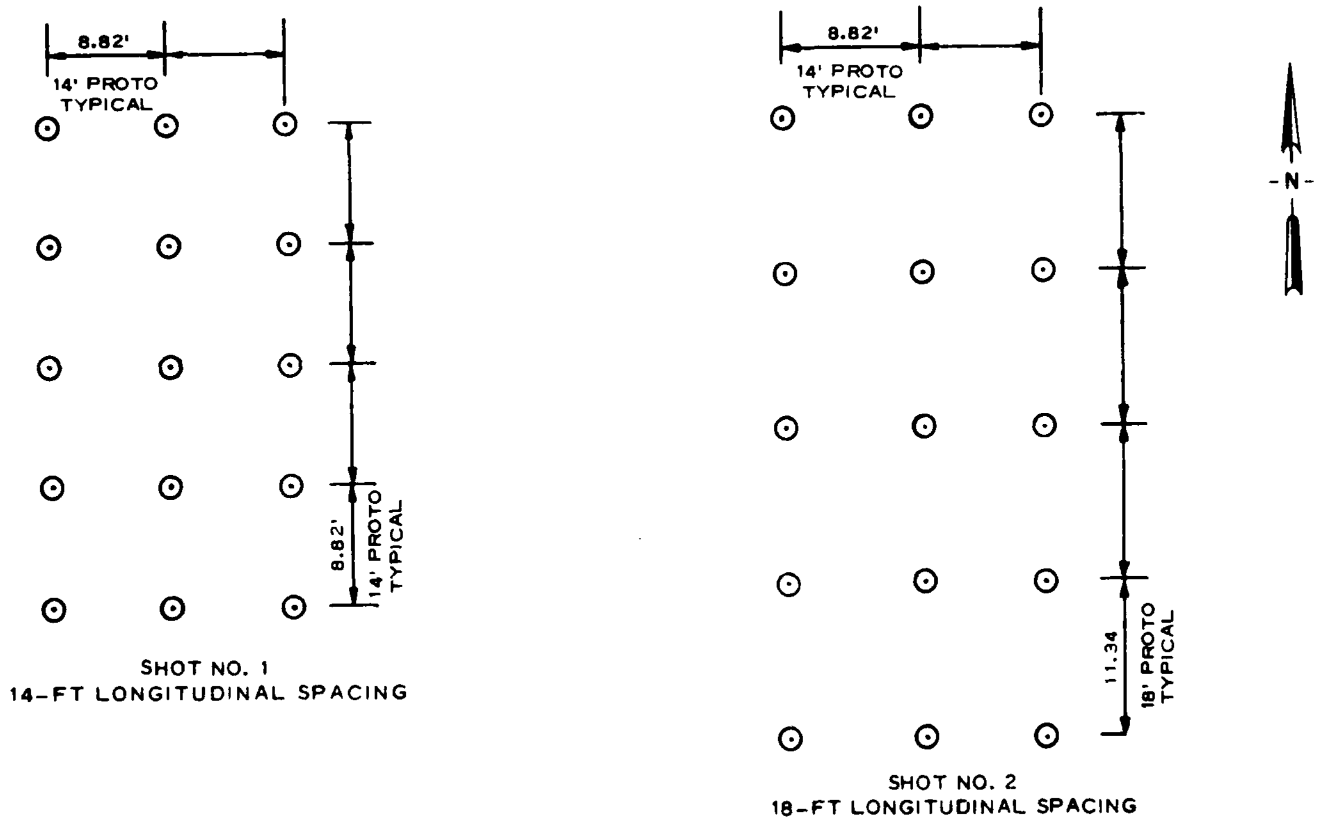

Figure 21. Plan view of Phase IV shots

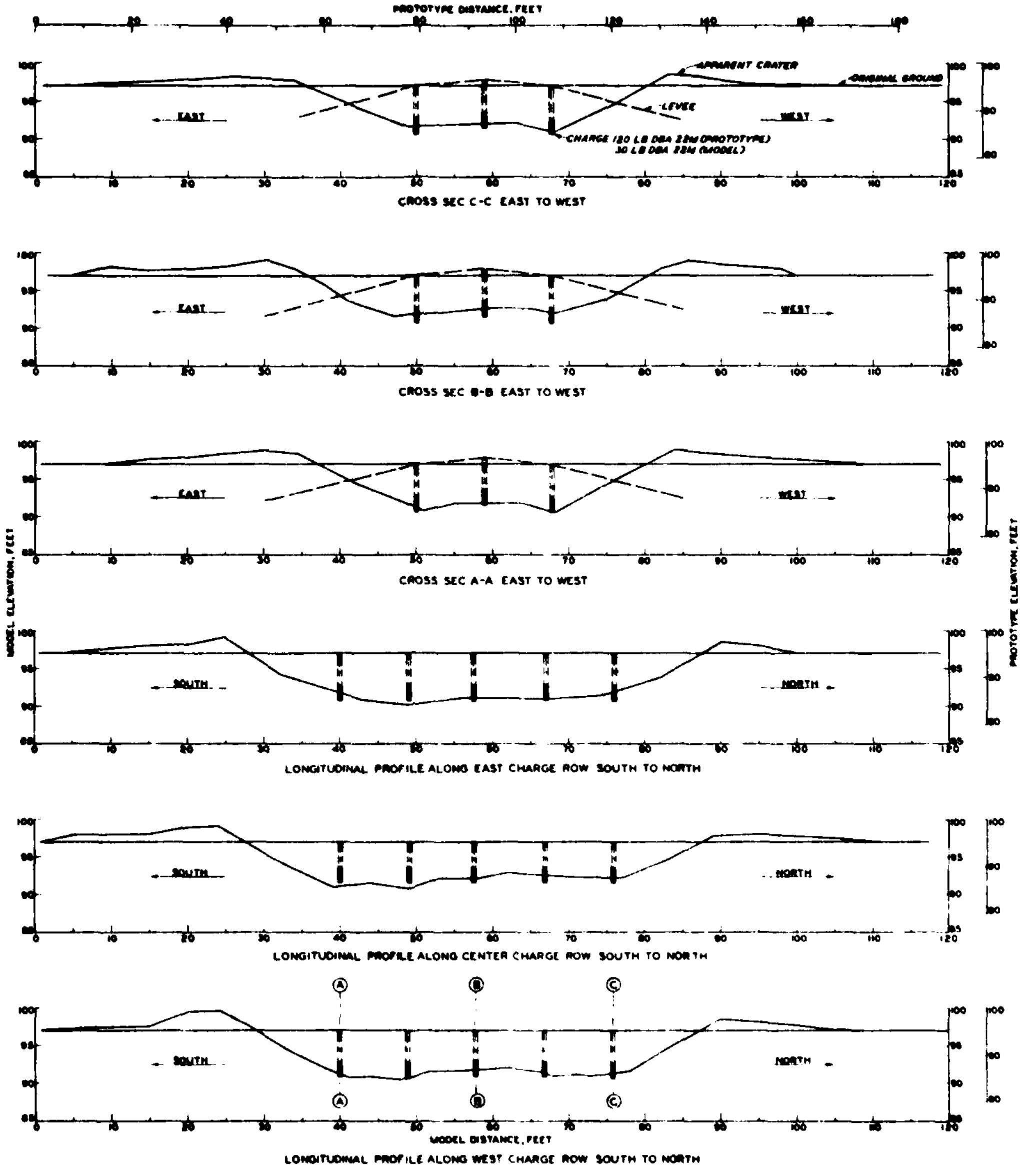

Figure 22. Phase IV ditch profiles, explosive design longitudinal spacing test, 8.82-ft (model), 14-ft (prototype) spacing

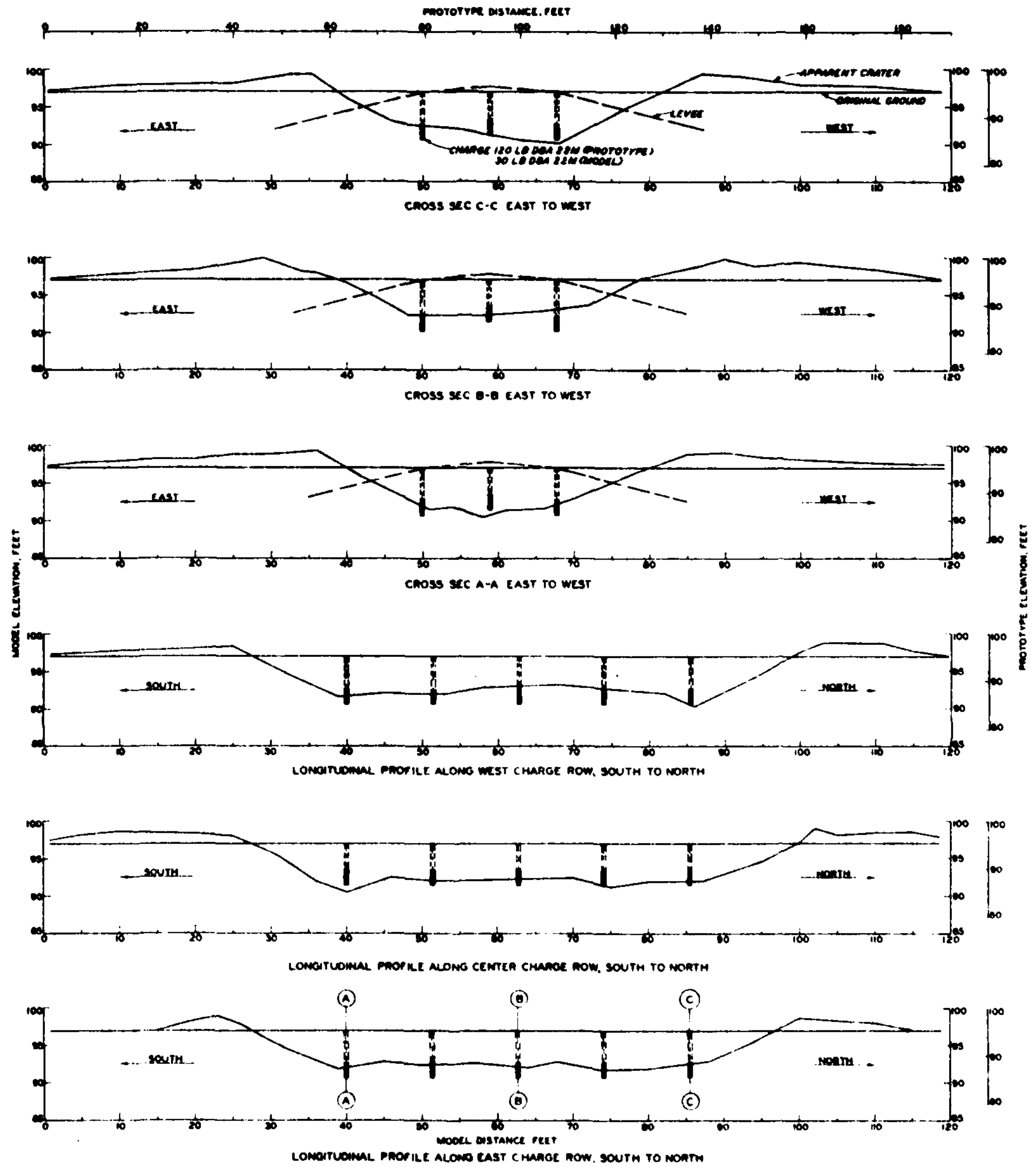

Figure 23. Phase IV ditch profiles, explosive design longitudinal spacing test, 11.34-ft (model), 18-ft (prototype) spacing

considered an upper limit, and that a spacing between 14 and 16 ft be selected. Further testing was not considered necessary, since refinements would be minor compared to the uncertainties regarding cratering and scour of the prototype levee.

26. MRC accepted the WES recommendations in a meeting held 18 October 1979, and agreed to termination of the test program. MRC requested that the problem of substitution of another slurry for the DBA 22M (if not available in sufficient quantity) be addressed in the WES summary of the test program.

PART III: SUBSTITUTION OF EXPLOSIVES

27. It may well be that a single explosive, or even a single supplier or manufacturer, will be unable to meet the demand that will accompany execution of the BP-NM Operation Plan. The following paragraphs discuss substitutes.

IRECO DBA105P

28. This pumpable slurry should be the first alternate to DBA 22M, and indeed may give better results (note characteristics in Table 1). It enjoys the added advantage of having been a part of another Corps of Engineers test program,* so it is a familiar product. If it is standardized as a military explosive, it should be substituted as the primary explosive slurry for BP-NM, but enough is known about it now to make its use perfectly acceptable. It should produce a deeper crater than DBA 22M at the same spacing. If, however, the manufacturer's capacity is exceeded, the slurry may not be available in sufficient quantity; there is probably only a small amount in storage at any time.

MS 80-20

29. The next alternative, MS 80-20, has also been tested in recent years.* It can be expected to perform well, with optimum DOB in a borehole about 9 ft in depth, producing a single crater with $r_a \approx 14$ ft for the 120-lb charge. Longitudinal spacing should be about 14 ft for best results. This situation can be improved by increasing the charge, providing the time and explosives are available to do this. If this option is chosen, it is recommended that the borehole depth again be placed at 10 ft and that two additional 30-lb bags be added, bringing the charge to 180 lb. The booster should still be between the bottom

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* Military Engineering Applications of Commercial Explosives (MEACE), currently being conducted by WES.

and second layer. This procedure should leave about 2.5 ft of open hole for stemming. The expected single-crater radius in the levee for the 180-lb charge is about 14.5 ft. Further improvement can be expected by staggering the MS 80-20 charges with the more energetic IRECO charges.

Hercules Flogel

30. This slurry exhibited a distinctly lower earth-moving capability than the foregoing candidates. Optimum borehole depth appears to be 7 to 8 ft, which should produce a crater with $r_a \approx 12$ ft . Accordingly, longitudinal spacing of about 12 ft is recommended. An irregular crater will probably result from the 14-ft transverse spacing. This and other low-energy charges can be improved slightly by the addition of more explosive, but cannot be brought up to desired standards within existing time and construction constraints. Again, staggering of these charges with a higher performance explosive will probably improve overall cratering performance.

Du Pont Tovex

31. Of the slurries fired in comparative tests, Tovex was the lowest performer. If its use becomes necessary, emplacement in a 6- to 7-ft borehole is recommended, which should result in $r_a \approx 11$ ft . Consideration should be given to a fourth row of boreholes across the levee, with transverse spacing = 7 ft. If this is possible, row-charge enhancement may permit longitudinal spacing to be held at 12 ft; this concept cannot be stated positively without testing. If the addition of a fourth transverse row is not possible, however, longitudinal spacing should definitely be reduced to 10-11 ft.

Other Slurries

32. Du Pont Pourvex, currently listed as the primary explosive in MDR 500-1-1, Appendix R, was not tested, and the Hercules Gel Power

was not tested as a single charge; thus, only the characteristics listed in Table 1 are available for a judgment on their relative merits. It appears that the Pourvex may be slightly preferable. If either is used, spacings discussed for the Tovex should be applied.

PART IV: RECAPITULATION OF RECOMMENDATIONS

Technical Recommendations

33. Major technical recommendations made by WES during the course of this program are recapitulated below:

a. The detonating cord layout contained in the operation plan is overly redundant, and should be retained only if time and logistical constraints can be resolved in such a manner as to leave no doubt that it can be installed without detriment to other parts of the plan.

b. In the levee cross section, the outside borehole on the river side should be as near the water as possible; this is taken to be the break point of the slope 14 ft from the levee centerline. This leads to a 14-ft spacing for the three-borehole design, which appears optimum for the leading slurry candidates.

c. The recommended heirarchy of slurry selection, with accompanying borehole depths and spacings, is shown below.

Order of Preference	Slurry	Borehole Depth, ft	Spacing: Transverse ft	Spacing: Longitudinal ft
1	DBA 22M	10	14	14-16
2	DBA 105P	10	14	14-16
3	MS 80-20	9	14	14
4	Flogel	7-8	14	12
5	Tovex	6-7	14	10-11
			7*	12
6	Pourvex	Same as Tovex		
7	Gel Power	Same as Tovex		

* Best results. Includes 4 rows of charges.

Nontechnical Recommendations

34. In addition to technical recommendations directly related to test design, WES furnished more general recommendations, based upon a review of the entire operation plan.* These are summarized below.

* Letter from Director, U. S. Army Engineer Waterways Experiment Station, CE, to President, Mississippi River Commission, Vicksburg, Miss., Subject: Review of Plan of Operation for Birds Point-New Madrid Floodway, 13 Apr 79.

a. Protection of the detonating cord layout is critical, and present plans to protect it appear inadequate.

b. The WES capability to support the plan with only its own personnel resources is doubtful. Recent discussion concerning the procurement of outside military assistance makes this option seem highly desirable. If this occurs, and if WES retains responsibility for execution of demolitions, detailed planning will be necessary to insure adequate supervision along with the preservation of unit integrity.

35. Since postshot scour is essential to levee removal, model tests of this phenomenon are recommended as the only means of confidently solving the problem. At the same time, discharge coefficients could be established which would permit accurate predictions of the effect of the levee breach.

36. A final recommendation is that available slurries and emplacement designs be re-examined periodically. The DBA 105P should be especially watched, with an eye toward a preemplaced pipe design that would both expedite execution of the plan and provide a much better breach.

REFERENCES

1. U. S. Army Engineer Waterways Experiment Station, CE. 1949. "Method of Operation of the Birds Point-New Madrid Floodway, Missouri," Technical Manual TM No. 2-300, Vicksburg, Miss.
2. U. S. Army Engineer Waterways Experiment Station, CE. 1957. "Operation of the Birds Point-New Madrid Floodway," Mississippi Basin Model Report No. 31-1, Vicksburg, Miss.
3. U. S. Army Engineer District, Memphis. 1978. "Emergency Employment of Army Resources, Natural Disaster Procedures Under PL 84-99 Operation of Birds Point-New Madrid Floodway," Appendix R to Supplement A to Engineer Regulation ER 500-1-1, Memphis, Tenn.
4. U. S. Army Engineer Waterways Experiment Station, CE. 1975. "Operation Plan for Breaching of the Upper Fuse Plug, Birds Point-New Madrid Floodway," Letter Report, Vicksburg, Miss.
5. U. S. Army Engineer Waterways Experiment Station, CE. 1961. "Cratering from High Explosive Charges: Analysis of Crater Data," Technical Report No. 2-547, Report 2, Vicksburg, Miss.

APPENDIX A: SCALING RELATIONS

Shown below are basic scaling relations of interest in the BP-NM study, tabulated by assumed scaling laws:

Measurement	Symbol	Scaling Ratios: Replica Scaling	Mach Scaling	Froude Scaling
Length	L	$L_m = nL_p$	$L_m = \frac{L_p W_m^{1/3}}{W_p^{1/3}}$	$L_m = nL_p$
Volume	V	$V_m = n^3 V_p$	$V_m = \frac{V_p W_m}{W_p}$	$V_m = n^3 V_p$
Weight (other than charge weight)	W'	$W'_m = n^3 W'_p$	$W'_m = \frac{W'_p W_m}{W_p}$	$W'_m = n^3 W'_p$
Speed or Velocity	v	$v_m = v_p$	$v_m = v_p$	$v_m = \sqrt{n}\ v_p$
Time	t	$t_m = nt_p$	$t_m = \frac{t_p W_m^{1/3}}{W_p^{1/3}}$	$t_m = \sqrt{n}\ t_p$
Discharge	Q	--	--	$Q_m = n^{5/2} Q_p$

Note: n = scale ratio model/prototype
W = charge weight
subscripts m = model
p = prototype

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Rooke, Allen D
  Birds Point-New Madrid Floodway emergency operation; explosive design summary / by Allen D. Rooke, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
  46, 2 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; SL-80-5)
  Prepared for Mississippi River Commission, Vicksburg, Miss.
  References: p. 46.

1. Birds Point-New Madrid Floodway. 2. Craters. 3. Explosive excavation. 4. Explosives. 5. Levee construction. I. United States. Mississippi River Commission. II. Series: Unted States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; SL-80-5.
TA7.W34m no.SL-80-5

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